

Minimum tillage systems and its effect on soil structure, humus conservation and water management

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1. Abstract

The purpose of this paper is to evaluate the soil properties of classic soil tillage systems versus three minimum soil tillage variants in the pedoclimatic conditions from Cluj-Napoca (46°46'N, 26°36'E), Romania. Our study presents the influence of a conventional plough tillage system on soil structure, humus and water conservation in comparison with alternative minimum tillage systems: paraplow, chisel plow and rotary harrow. Minimum tillage, with or without straw, resulted in enhanced soil moisture conservation and moisture availability during crop growth. Availability of soil moisture during the crop growth resulted in better plant water status. Straw mulch at the variant minimum tillage conserved more water in the soil profile during the early growth period compared to conventional tillage. Subsequent release of conserved soil water regulated proper plant water status, soil structure, and lowered soil penetrometer resistance. The practice of reduced tillage is ideal for enhancing soil fertility, water holding capacity, and reducing erosion.

2. Introduction

The long use of soils in conventional agriculture, which was intensive and excessively subjected to mechanical and chemical treatment, has its contribution to their degradation: the structure is damaged, the humus content falls, the soil became acid, the compaction grows, the permeability is reduced etc. On the other hand, the correct use of fertilisers, amendments and other agrotechnical and pedologic measures can improve the fertility indices of arable soils, with positive effects. The influence of cultivation on soils is undisputable, but it is differentiated by the type and intensity of applied technology. Conventional tillage means, in Romania as elsewhere, the autumn plough tillage at approximately 20-25 cm, followed by disc harrow work in the spring and sowing fertilizer and seed via drill. This practice accounts for a number of problems such as soil degradation, erosion, compaction and waterway pollution (Gus, 1997; Rusu, 2001; Jitareanu et al., 2006). While conventional soil tillage (basic working, preparation of the germinal layer, maintenance of the field, etc.) results in immediate positive effects, some negative effects also manifest themselves. One of the main objectives for the soil tillage system is to create an optimal physicochemical state of the soil and to preserve this state over the whole vegetation period. This study, conducted under different bioclimatic conditions, shows that the soil tillage system directly influences soil properties (Dick et al., 1994; Moirizumi and Horino, 2002; Mark and Mahdi, 2004; Feiza et al., 2005; Riley et al., 2005; Ulrich et al., 2006).

3. Methods

Our study presents the influence of a conventional plough tillage system on soil structure, humus and water conservation in comparison with alternative minimum tillage systems: paraplow, chisel plow and rotary harrow (which 30% of the crop residue remains on the soil surface). The influence of tillage soil system upon soil structure, humus and water conservation was studied on several soil types (Table 1, MESP, 1987; SRTS, 2003) at the University of Agricultural Sciences and Veterinary Medicine of Cluj Napoca. The tests were conducted between 1996 and 2007.

The experimental soil tillage systems were as follows:

Classic system: V₁ – classic plough + disc – 2x,

Minimum tillage systems: V₂ – paraplow + rotary harrow,

V₃ – chisel plow + rotary harrow,

V₄ – rotary harrow.

To quantify the change in soil properties under different tillage practices, determinations were made for each cultivar (maize - *Zea mays* L., soy-bean - *Glycine hispida* L. Merr., wheat - *Triticum aestivum* L., spring rape - *Brassica napus* L. var. *oleifera* D.C. / potato – *Solanum tuberosum* L.) in four vegetative stages (spring, 5-6 leaves, bean forming, harvest). Soil parameters monitored included soil water content (gravimetric method, Aquaterr probe - Frequency domain reflectometry), soil bulk density (determined by volumetric ring method

using the volume of a ring 100 cm³), soil penetration (using a Fieldsout SC900 penetrometer), water stable aggregates, soil permeability (using the Infiltrometer method) and humus content. The average result values, obtained in the vegetal phases were statistically processed, taking into consideration the last four cultivation years within the crop rotation for every type of soil. The results were statistically analysed by ANOVA and Duncan's test (PoliFact, 2002). A significance level of $P \leq 0.05$ was established a priori.

Table 1 Initial select soil properties (0-20 cm) on different soil types at the experimental area near the University of Agricultural Sciences and Veterinary Medicine, Cluj Napoca, Romania

Type of soil (WRB-SR, 1998)	Clay content, %	Humus, %	WSA, %	pH	P.m.m., mm	T.m.m., °C
Chernozem cambic	43.1	3.52	78	6.73	500	8.8
Phaeozem tipic	43.2	3.92	76	6.71	500	8.8
Haplic luvisols	42.0	2.49	65	6.06	613	8.2
Fluvisol molic	41.6	3.01	61	7.25	613	8.2

WSA - Water stability of structural macro-aggregates; P.m.m. - Precipitation medium multi-annual; T.m.m. - Temperature medium multi-annual.

4. Results

Long-term field experiments provide excellent opportunities to quantify the long-term effects of soil tillage systems on soil structure, humus and water conservation. The hydrological function of the soil (especially the capacity to retain an optimum water quantity, and then gradually make this available for plant consumption) is one of the most important functions determining soil fertility, bioproductive capacity, and soil evolution. Intrinsic soil properties such as humus content and texture, along with applied tillage practices combine to modify the soil structure, porosity, permeability and water capacity. This, in turn, is a critical factor in the water cycle and affects water accumulation in the soil.

Statistical analysis of the results showed that the differences in accumulated soil water depended on the variants of soil tillage and type of soil. Soil texture and structure have a strong effect on the available water capacity. The results clearly demonstrate that minimum tillage systems promote increased humus content (0.8-22.1%) (Table 2) and increased hydro-stable aggregate content (1.3-13.6%) (Table 3), at the 0-30 cm depth compared to conventional tillage.

Table 2 The influence of soil tillage system upon humus content (H., %; 0-30 cm)

Type of soil	Soil tillage systems	Classic plough + disc -2x	Paraplow + rotary harrow	Chisel plow + rotary harrow	Rotary harrow
Chernozem cambic	Humus, %	3.51 a	3.54 a	3.87 a	3.61 a
	Signification (%)	wt ⁰ (100)	ns ⁰ (100.8)	ns ⁰ (110.2)	ns ⁰ (102.8)
Phaeozem tipic	Humus, %	3.90 a	4.13 b	3.93 ab	3.98 ab
	Signification (%)	wt ⁰ (100)	*(106.0)	ns ⁰ (100.9)	ns ⁰ (102.2)
Haplic luvisols	Humus, %	2.48 a	2.94 ab	3.02 b	2.82 ab
	Signification (%)	wt ⁰ (100)	*(118.6)	*(122.1)	ns ⁰ (113.9)
Fluvisol molic	Humus, %	3.03 a	3.12 ab	3.09 ab	3.23 b
	Signification (%)	wt ⁰ (100)	ns ⁰ (103.1)	ns ⁰ (102.0)	ns ⁰ (106.5)

Note: wt – witness, ns – not significant, * signification positives, ⁰ signification negatives, a, ab, b, c - Duncan's classification.

Statistical analysis regarding the humus content of studied systems shows significant positive values on Haplic luvisols under paraplow and chisel tillage as well on typical Phaeozems under paraplow and rotary harrow tillage. Multiple comparisons between systems indicate advantages for using the paraplow on Phaeozems (b), chisel on Haplic luvisols (b) and rotary harrow molic Fluvisol (b). Multiple analysis of soil classification and tillage system on the hydric stability of soil structure have shown that all variants with minimum tillage are superior (a, b, c), having a positive influence on soil structure stability.

The increase of organic matter content and humus content is due to the vegetal remnants partially incorporated and adequate biological activity in this system. In the case of humus content and also the hydro stability structure, the statistical interpretation of the dates shows an increasing positive significance of the minimum tillage systems application. The soil fertility and hydro stability of the macro-aggregates were initially low, the effect being the conservation of the soil features and also their reconstruction, with a positive influence

upon the permeability of the soil for water. More aggregated soils permit more water to reach the root zone. This not only increases productivity, it may also reduce runoff, and thus erodibility potential.

Table 3 The influence of soil tillage system upon water stability of structural macro-aggregates (W.S.A., %; 0-30 cm)

Type of soil	Soil tillage systems	Classic plough + disc –2x	Paraplow + rotary harrow	Chisel plow + rotary harrow	Rotary harrow
Chernozem cambic	W.S.A., %	74.33 a	79.00 b	78.67 ab	80.33 b
	Signification (%)	^{wt.} (100)	* (106.3)	^{ns} (105.8)	* (108.1)
Phaeozem tipic	W.S.A., %	80.00 a	82.33 b	81.00 ab	81.67 ab
	Signification (%)	^{wt.} (100)	* (102.9)	^{ns} (101.3)	^{ns} (102.1)
Haplic luvisols	W.S.A., %	63.67 a	68.33 b	66.67 ab	72.33 c
	Signification (%)	^{wt.} (100)	* (107.3)	* (104.7)	** (113.6)
Fluvisol molic	W.S.A., %	71.33 a	76.00 b	75.33 b	76.33 b
	Signification (%)	^{wt.} (100)	* (106.5)	* (105.6)	* (107.0)

The minimum soil tillage systems and the replacement of ploughing by paraplow, chisel and rotary harrow work minimise soil aeration. The bulk density values at 0-50 cm (Table 4) increased by 0-4.7% under minimum tillage systems. This raise was not significant in any of the experimental variants. Multiple comparing and classification of experimental variants align all values on the same level of significance (a).

Table 4 The effect of soil tillage system on the bulk density (B.D., g/cm³, 0-50 cm)

Type of soil	Soil tillage systems	Classic plough + disc –2x	Paraplow + rotary harrow	Chisel plow + rotary harrow	Rotary harrow
Chernozem cambic	B.D., g/cm ³	1.32 a	1.38 a	1.37 a	1.36 a
	Signification (%)	^{wt.} (100)	^{ns} (104.7)	^{ns} (103.9)	^{ns} (103.3)
Phaeozem tipic	B.D., g/cm ³	1.22 a	1.23 a	1.25 a	1.22 a
	Signification (%)	^{wt.} (100)	^{ns} (100.8)	^{ns} (101.9)	^{ns} (100.0)
Haplic luvisols	B.D., g/cm ³	1.32 a	1.35 a	1.34 a	1.35 a
	Signification (%)	^{wt.} (100)	^{ns} (102.4)	^{ns} (101.7)	^{ns} (102.4)
Fluvisol molic	B.D., g/cm ³	1.34 a	1.34 a	1.35 a	1.34 a
	Signification (%)	^{wt.} (100)	^{ns} (100.0)	^{ns} (100.6)	^{ns} (100.0)

The soil resistance to penetration, presented as an average of determinations on the four types of soil, shows a stratification tendency of soil profiles within the plough variant, where values are under 1000 kPa up to the 20-22 cm depth and then suddenly increase over 3500 kPa below this depth. The significant differences were determined in the minimum tillage systems at 10-20 cm, where the values of resistance to penetration range between 1500-2500 kPa. Thus, in the variants worked with minimum tillage system, the soil profile stratification is significantly reduced.

After ten years of applying the same soil tillage system, the data show that soil infiltration and soil water retention are higher when working with paraplow and chisel plow variant with values of 5.54 (c) and 5.08 (b) l/m²/min, respectively. By contrast, the amount of water retained by traditional tillage was 4.25 (a) l/m²/min. The paraplow and chisel plow treatments were more favourable for infiltration and water retention. Positive effects on the saturated hydraulic conductivity of the paraplow (35.7 cm/h) and chisel plow (31.5 cm/h) treated soils were observed compared with the traditional tillage (29.4 cm/h) of the soil.

On haplic Luvisols, a soil with a moderately developed structure and average fertility, the quantity of water accumulated was 1-6% higher under paraplow (b), chisel plow and rotary harrow tillage, compared to conventional tillage (Table 5). On molic Fluvisols and cambic Chernozems, soils with good permeability, high fertility, and low susceptibility to compaction, accumulated water supply was higher (representing 11-15%) for all minimum soil tillage systems. In the four soils tested, the paraplow was the better at water conservation (as evidenced by multiple comparisons and variants – b, c), showing an increase in the water reserve in soil of 4.8-12.3%.

5. Conclusions

Reduced tillage systems represent an alternative to conventional tillage. This study demonstrated that increased humus content, soil structural aggregation, and increased soil permeability are all promoted by minimum tillage systems. The implementation of such practices ensures a greater water reserve even across different soil types. The practice of reduced tillage is ideal for enhancing soil fertility, water holding capacity,

and reducing erosion. The advantages of minimum soil tillage systems for Romanian pedo-climatic conditions can be used to improve methods in low producing soils with reduced structural stability on sloped fields, as well as measures of water and soil conservation on the whole ecosystem.

Table 5 The effect of soil tillage system on the water supply accumulated in soil (W, m³/ha; 0-50 cm)

Type of soil	Soil tillage systems	Classic plough + disc –2x	Paraplow + rotary harrow	Chisel plow + rotary harrow	Rotary harrow
Chernozem cambic	W, m ³ /ha	936 a	1.051 b	1.047 b	1.039 b
	Signification (%)	^{wt.} (100)	*(112.3)	*(111.9)	*(111.0)
Phaeozem tipic	W, m ³ /ha	842 a	882 b	875 a	859 a
	Signification (%)	^{wt.} (100)	*(104.8)	^{ns} (103.9)	^{ns} (102.0)
Haplic luvisols	W, m ³ /ha	850 a	901 b	870 a	859 a
	Signification (%)	^{wt.} (100)	*(106.0)	^{ns} (102.3)	^{ns} (101.0)
Fluvisol molic	W, m ³ /ha	878 a	1.010 c	998 b	987 b
	Signification (%)	^{wt.} (100)	*(115.0)	*(113.7)	*(112.4)

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